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Experiment Protocol Boosters Over Inmarsat-ISDN Communication Link

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14. ABSTRACT
The International Maritime Satellite (Inmarsat) communication service can be used to provide a wide area network (WAN) connection for a local area network (LAN) to the home LAN from almost anywhere on the earth. The communication link of the WAN connection is achieved through the satellite network of Inmarsat and a land-earth digital telephone network, such as Integrated Services Digital Network (ISDN). We determined the throughput data rate of data transmission in the Transmission Control Protocol/Internet Protocol (TCP/IP) environment over the Inmarsat link and compared it with the throughput data rate over a null-modem link (assumed to be error free) for the WAN connection. We also used the protocol boosters that provide forward error correction for the TCP/IP environment to test the improvement of data transmission over the satellite link. Communication over satellite tends to be noisy and delay prone. However, our analysis shows that the Inmarsat satellite-ISDN link is so reliable that the data transmission rate is nearly an error-free link in the TCP/IP network, and the application of forward error correction on the network causes a reduction in the throughput data rate.

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Satellite communications, Inmarsat, ISDN data transmission, protocol boosters

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Contents

List of Figures

List of Tables

1. Introduction

Wireless communications, especially with satellite networks, tend to be labeled noisy, highly delayed, and costly. On the other hand, wireless satellite communications provide some benefits such as convenience, mobility, and flexibility in accessing the service. In some cases, it is cost effective to use the service if there is no existing communication infrastructure available. There are both military and commercial applications that use the digital data service of the International Maritime Satellite (Inmarsat) to provide a wide area network (WAN) link for a local area network (LAN) to the home LAN from almost anywhere on the earth, except areas near the north and south poles. The communication link of the WAN connection is achieved through the satellite network of Inmarsat and a land-earth digital telephone network, such as Integrated Services Digital Network (ISDN). To determine how well the wireless satellite service works, we evaluated the throughput rate of data transmission in the Transmission Control Protocol/Internal Protocol (TCP/IP) environment (which is used by the IP WAN) over the International Maritime Satellite (Inmarsat)-ISDN link and compared it with the throughput data rate over a null-modem link for the WAN connection. The null-modem link is assumed to be error free. In addition, we also used the protocol boosters [1] that provide forward error correction for the TCP/IP environment to test the improvement of data transmission over the satellite link. As expected, the forward error correction will improve data transmission if the bandwidth used for forward error correction is less than the bandwidth used for retransmission due to error on the link. To accurately measure the TCP and user datagram protocol (UDP) performance over IP with these protocol boosters, we used the software Test Transmission Contro Protocol (TTCP), which is in the public domain.

2. Background

2.1 Inmarsat

Inmarsat is the communication service provided by the International Maritime Satellite organization. In 1979, a consortium of 79 countries established the Inmarsat organization to serve the maritime industry. The organization operates and governs a global satellite system consisting of four satellites in geostationary orbit to provide voice, fax, analog data, and digital data communications for maritime customers on the move or in remote locations. Today, its function has expanded to include services for land, mobile, and aeronautical communications along with personal and multimedia mobile satellite communications. Its global satellite system

has grown to nine geostationary satellites to provide all the services as before but also to allow spares or leased capacity and to operate a number of spot beam "cells" that enable the satellites to concentrate extra power in areas of high demand [2]. There are about 40 land-earth stations (LES) [2] that provide communications in between Inmarsat satellites or between Inmarsat satellites and land-earth communication networks.

An Inmarsat communication link can be initiated from a mobile satellite communication unit (MSU) by transmitting signals to a satellite of the Inmarsat satellite network. Upon receiving the signals, the Inmarsat satellite transmits them to an LES specified by the initiator MSU. The LES then sends the signals through a land-earth telephone network to a destination source in the telephone network. To establish a digital data communication link with an MSU, the destination source must be connected to a land-earth digital phone network, such as an ISDN. A regular phone source can also be linked to an MSU by reversing this process.

In our experiment, we used a Rockwell DATA*SAT satellite communications (SATCOM) unit with the "Inmarsat-B" service [3]. The high-speed digital data service of the SATCOM unit used the Inmarsat satellite AOR-W (Atlantic Ocean – West), the LES of COMSAT Mobile Communications, and the USA national ISDN with Worldcom/MCI as long distance carrier and Verizon as local carrier. The Inmarsat-B service can provide 9.6-kbps analog communication (for voice, fax, and data) and high-speed digital data communication at 56/64-kbps data rate.

2.2 Protocol Boosters

The protocol boosters are a collection of parasitic modules (which can be software or hardware) that transparently enhance communication protocols [1]. The boosters can reside anywhere in the network, operating independently in one network node (single element booster) or being distributed over several network nodes (multi-element booster). They can add, delete, or delay end-to-end protocol messages but never modify the syntax or semantics of the end-to-end protocol message exchanges. The insertion or removal of protocol boosters does not prevent end-to-end communications.

In the experiment, we installed the protocol boosters developed by Telcordia Technologies on the two Linux operating systems running kernel level 2.0.32. The two primary booster modules used in the experiment were forward erasure correction (FZC) and packet resizer (MSS). We also used the (DROP) booster module to simulate packet error. The DROP booster is a single element booster and should be installed on a network node along the network path of communication. The network node with DROP booster setup will drop packets (instead of forwarding packets) based on a specified percentage.

The forward erasure correction booster is implemented by having one system with an FZC module doing the encoding and another system with an FZC module doing the decoding. The encoder system generates parity packets and inserts them into the data stream. The decoder system uses the minimum, necessary number of received packets (some original packets and

some parity packets, assuming some lost packets) to reconstruct the original data stream. For example, with FZC:k-h parameter, when forwarding k data packets from the sender, the encoder adds h parity packets and transmits them all. When receiving packets, the decoder reconstructs the original k data packets from any k packets of received packets, which might be less than or equal to k+h but must be greater than or equal to k, and forwards the reconstructed k data packets to the destination receiver [4]. If the number of corrupted or missed packets is greater than h, then the reconstruction of the original k packets cannot be done and retransmission must be performed. When encoding to generate packets, the FZC booster adds 16 bytes of its overhead information to every packet.

Because of the 16-byte overhead of FZC, the network packet size might exceed the maximum transfer unit (MTU) of the Ethernet interface, 1500 bytes (1460 bytes of payload and 40 bytes of TCP/IP header). Therefore, we need to use the packet resizer booster, MSS, to constraint the maximum data packet size of TCP/IP by modifying the advertisement of the maximum segment size of TCP protocol during the TCP's initial three-way handshake. To maintain the MTU at 1500 bytes, we use the MSS booster to reduce the normal maximum segment size by only 16 bytes, which compensates for the 16-byte overhead of FZC. Therefore, in the experiment, with the use of MSS and FZC boosters, the actual maximum data packet size is 1432 bytes after excluding overheads.

2.3 TTCP

The protocol boosters have some limitations that prevent them from working properly with some TCP/IP applications such as file transfer protocol (FTP) software. Therefore, to test data transmission, we used the program TTCP, which is public domain software and works properly with the protocol boosters on a Linux platform. TTCP can time the transmission and reception rate of data transfer between two systems using either UDP or TCP protocol. In the experiment, we used TTCP in TCP mode to measure the data transfer rate over two nodes using Linux operating systems. We notice that on every data transfer, the transmission rate is slightly higher than the reception rate. For consistency and completeness of the data transfer, we choose reception rate as the data transfer rate.

3. Experiment

3.1 Setup

Figure 1 depicts the setup of the experiment. The two end systems of the communication test are Linux workstations, Sender and Receiver with IP addresses 172.31.1.40 and 172.16.0.40,

respectively. The gateway routers for the two LANs, S and R, which are 100-Mbps Ethernet networks, are Linux systems with protocol boosters, called Linux-booster1 and Linux-booster0, respectively. Those gateways are in turn linked with a 10-Mbps Ethernet connection to Cisco 1600 routers, Router1 and Router0. The Router1 connects to a Rockwell MSU through an RS449 interface. The Router0 has ability to connect to the USA National ISDN. The WAN connection using the Inmarsat communication channel and ISDN links the two Cisco routers together (two LANs, 192.168.1.0 and 192.168.0.0). The Inmarsat service used for the experiment is a 64-kbps digital data channel. The data transmission travels from Sender, to Linux-booster1, to Router1, to MSU, up to the Inmarsat AOR-W satellite, down to the LES of COMSAT Mobile Communications, to the USA national ISDN phone network, to Router0, to Linux-booster0, and to Receiver. There are no other network nodes on any LANs of the experiment to affect the data communication of Sender and Receiver.

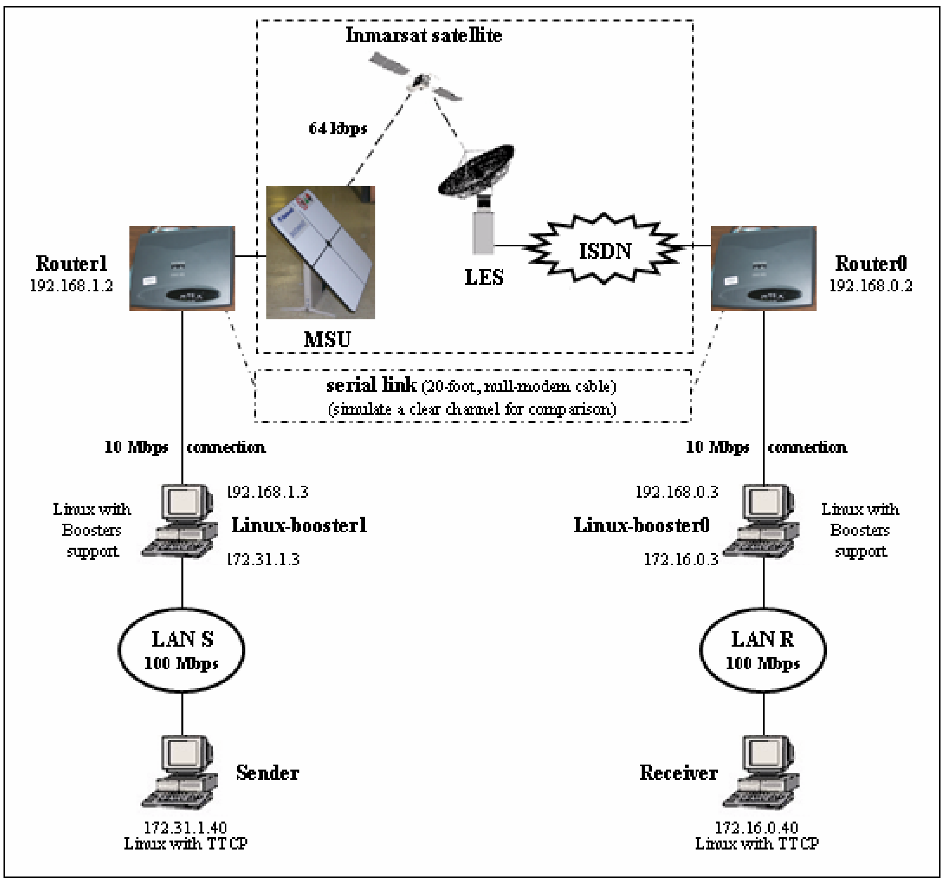

Figure 1. Experiment setup.

To simulate a clear channel for comparison, we use a null-modem serial link to connect Router1 and Router0 (Cisco routers). The null-modem serial link replaces the Inmarsat-ISDN link. The bandwidth of the serial link of two Cisco routers is set to 64 kbps, which is the same bandwidth of the Inmarsat channel. The same point-to-point protocol (PPP) encapsulation is used on the Cisco routers for the serial link and the Inmarsat-ISDN link.

3.2 Booster Parameters

As determined in section 2.2, when using MSS and FZC boosters, the maximum data packet size that can be used for data transmission is 1432 bytes. Next, we need to determine the optimum data packet size and data-parity ratio to use in the Inmarsat-ISDN channel, but we do not know how bad or good the channel is. We assume that the ISDN segment link of the channel is clean because it is digital and wired communication. Therefore, we tune parameters to best fit the satellite link. Because the forward erasure correction booster reconstructs the entire corrupted or lost packet rather than correcting some individual bits of the packet, we decided to use the largest data packet size, which is 1432 bytes, to minimize the overhead of data transmission. Also, the findings of the experiment of Bakin, Joa-Ng, and McAuley [5] indicate that reducing packet size has very little effect on the throughput data rate over a geostationary satellite link. Hence, with all data and network overhead, the network packet size (Ethernet packet size) is 1500 bytes.

Because the Inmarsat service is very costly (~$10/min) and there are many combinations of data and parity that can be used for FZC to test the satellite link, we designed a packet-error simulation by using DROP booster and the serial link. We assume that the null-modem serial connection between Cisco routers is error free (during the time of the experiment). The DROP booster is installed on the same machine that encodes FZC packets, Linux-booster1. We use the DROP booster to drop packets to simulate packet losses. The packet error rate (PER) can be derived approximately from the bit error rate (BER) by the formula: PER = BER × Packet Size. For example, the PER corresponding to a 1e-6 BER with a packet size of 1500 bytes (12000 bits) is 0.012 or 1.2%. To simulate packet transmission errors, we let the DROP booster randomly drop packets based on specified percentages corresponding to the desired PERs.

We perform the 5-MB data transmission using a data packet size of 1432 bytes (or network packet size of 1500 bytes) for no FZC and 4 FZC cases: FZC:4-1, FZC:3-1, FZC:3-2, and FZC:1-4. We plot the data rates of cases against the percentage of packet drop, as depicted in Figure 2. We notice that FZC:4-1 has the best data rate among other FZCs for packet-drop percentage below 23%, which corresponds to a BER of 1.9e-5. No transmissions with FZC are any better than the transmission without FZC and with a BER less than 1.9e-5. Therefore, we choose the FZC:4-1 parameter to test the effect of the protocol boosters on the Inmarsat satellite link.

We should note that a router having different interface speeds can drop packets if the fast interface passes to the slow interface too many packets that the slow interface cannot handle. In the experiment, the Linux-booster0 or Linux-booster1 has two interfaces with speeds of 100 Mbps and 10 Mbps. At the Router0 and Router1, there are two different speed interfaces, 10 Mbps and 64 kbps. Although cache buffer and flow control of TCP/IP can mitigate the problem, packet drops can still happen.

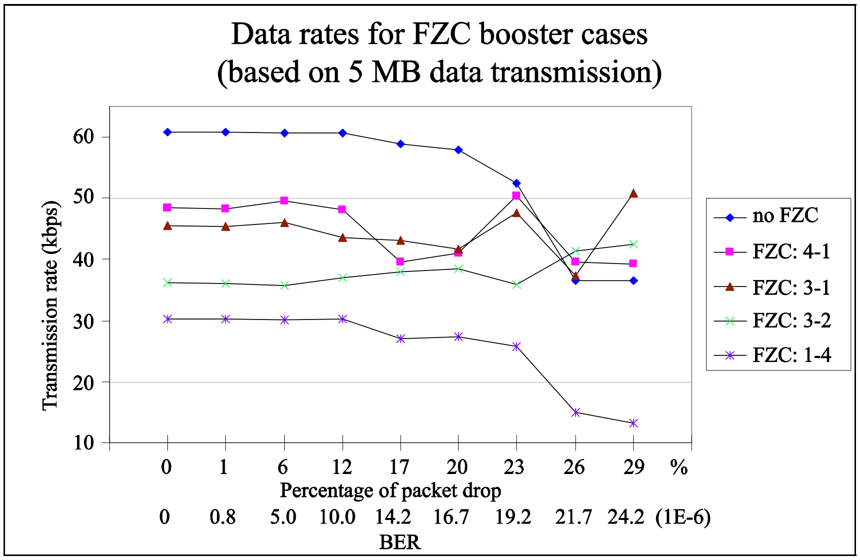

Figure 2. Packet error simulation.

The constraints of maximum data packet size of 1432 bytes and the transmission of encoded FZC:4-1 packets are negotiated and performed by the Linux-booster0 and Linux-booster1. The Sender and Receiver are unaware of all actions of the protocol boosters.

3.3 Results

In the experiment, we tested the transmission of 1-MB, 5-MB, and 10-MB data through the Inmarsat satellite link and through the serial link. We also used the FZC booster with 4-1 parameter (1 parity packet for every 4 data packets) to test the transmissions of the same set of data and links. All the tests were performed under fair weather conditions (sunny or cloudy, but not rainy) and temperatures ranging from typical winter season temperatures to typical summer season temperatures.

Table 1 lists the results of transmission times for all cases. The serial link is assumed to be error free (for the duration of the experiment) because it uses a wired Cisco serial connection with a wire length of 20 ft. It is used as a reference for comparison. Table 2 shows the data rate comparison with the 5-MB-serial-no-boosters case for all cases.

Table 1. Transmission time (seconds) using TTCP.

Link types	**Data sizes**		
	1 MB	**5 MB**	**10 MB**
serial – no boosters	137.89	689.39	1378.90
serial – FZC:4-1	173.12	864.82	1729.41
Inmarsat – no boosters	138.98	690.64	1380.35
Inmarsat – FZC:4-1	173.67	865.64	1730.09

Table 2. Data rate comparison with 5 MB-serial-no-boosters transmission.

Link types	Data sizes		
	1 MB	5 MB	10 MB
serial – no boosters	99.99%	100%	99.99%
serial – FZC:4-1	79.64%	79.71%	79.73%
Inmarsat – no boosters	99.21%	99.82%	99.89%
Inmarsat – FZC:4-1	79.39%	79.64%	79.69%

Figure 3 shows that the data transmission rate over the serial link without boosters is almost constant regardless of the size of the data. The results also show that the data transmission over the Inmarsat without boosters is very close to that of the error-free channel (more than 99%). When comparing the data transmission rate of the Inmarsat with boosters and the rate of the serial link with boosters, we notice the same closeness (more than 99.5%). This closeness in the transmission rates of Inmarsat and serial link in various data sizes and with or without boosters indicates that their performance is almost the same. Hence, the 64-kbps digital data channel of Inmarsat is very clear and stable with a very low BER.

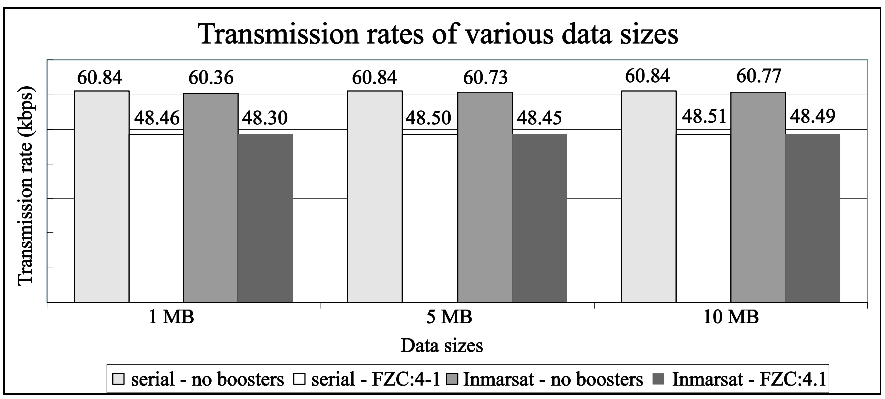

Figure 3. Transmission result.

Clearly, based on the data collected, the protocol boosters do not improve the performance of TCP over the satellite link. The transmission rate using boosters only achieves <80% of the data rate without using them. The low data rate performance associated with boosters in either serial or Inmarsat link clearly indicates that for a very low BER channel, the extra FZC parity packets just add to the overhead of transmission.

3.4 Discussion

The ratio of parity packet over data packet for using FZC:4-1 is 0.25 or 25%; therefore, to see any benefits of using FZC:4-1 booster, the PER should be greater than 0.25 or 25%. Indeed, our packet error simulation plotted in Figure 2 confirms this point as shown at 23% and 26%.

We also notice that in Figure 2, with a PER of 6% (or BER of 5e-6) or less, the reduction of data transmission rates of FZC cases, except the FZC:1-4 case, scale with the percentage of parity packets in the total transmitted packets (data and parity) when compared with data rate of no FZC case. For example, for the FZC:4-1 booster (one parity packet for every four data packets), the percentage of parity is 20%, and the throughput reduction is 20% compared to no FZC case. We don't know why the FZC:1-4 case performs differently, but we did have to prepare the FZC booster differently for the FZC:1-4 case as instructed by the author of the protocol booster software. We suspect that there are errors (operator or software) in the FZC:1-4 case because its data rate did not perform as expected for higher PER. This finding of the simulation indicates that for a channel with low BER (even with 5e-6), the FZC booster does not boost the throughput but causes throughput reduction based on the percentage of parity encoded. This finding was also reflected on the data collected in our experiment for throughput performance of serial link and Inmarsat link. With this, we can conclude that the Inmarsat link has a very low BER because its throughput performance is very close to the throughput of the serial link. Also, because the Inmarsat channel performed consistently for the long duration of 10-MB data transmission (29 min), we believe that there is little error bursting in the channel.

We further tested the effect of parity percentage on the throughput reduction for the Inmarsat link by varying FZC booster parameters, as shown in Table 3. As expected, the test does show that for a very clear channel, the bandwidth used for forward error correction is lost (because there are very little of errors to correct) and reduces the available bandwidth of the channel for data transmission with that same amount. Remarkably, the throughput reduction still follows the trend for the percentage of parity at 0.5, 1, and 2%. With this test, we can again confirm that the Inmarsat-ISDN channel is nearly an error-free link. Also, based on this result, we should note that the percentage of parity encoded by the FZC booster will limit the maximum throughput rate of data transmission regardless of how good or bad the channel is. For example, with FZC:4-1, the percentage of parity is 20%; thus the maximum throughput rate for the data transmission using FZC:4-1 booster can only be 80% of the throughput data rate for the error-free transmission on the same channel.

Table 3. Reduction in data rate with increase parity on the Inmarsat link.

FZC Parameters	Percentage of Parity	5-MB Transmission Time (s)	Computed Throughput Data Rate (kbps)	Percentage Reduction Of Throughput Data Rate
No booster	0%	690.64	60.73	0.00%
199-1	0.5%	694.75	60.37	0.59%
99-1	1%	698.36	60.06	1.11%
49-1	2%	705.02	59.49	2.04%
19-1	5%	727.59	57.65	5.08%
9-1	10%	768.78	54.56	10.16%
4-1	20%	865.64	48.45	20.22%
3-1	25%	923.58	45.41	25.22%
3-2	40%	1158.00	36.22	40.36%
1-1	50%	1383.12	30.32	50.07%

Although our communication channel is only 64 kbps, the throughput data rate of data transmission using TTCP can achieve 60.7 kbps. A bandwidth of <4 kbps (or 6.25%) is used for the overhead of TCP/IP. We notice that there are small fluctuations on throughput rates for the use of boosters on both channels. The fluctuation can be due to the use of some CPU time to do FZC encoding and decoding on the Linux-booster0 and Linux-booster1, which act as routers. The small fluctuation on the throughput rate of the Inmarsat-ISDN link without boosters can be attributed to the long delay and processing of many different pieces of equipment (e.g., MSU, Inmarsat satellite, LES, WorldcomMCI ISDN switch, and Verzion switch). Overall, these fluctuations are insignificant and are minimized on average for long durations of transmission as seen in the 10-MB data transmission. However, a very windy condition can affect the standing position of an Inmarsat MSU (which requires steadiness); this, in turn, can cause fluctuations on the Inmarsat service.

4. Conclusion

Our experiment has shown a versatile way of using the Inmarsat communication service as a WAN connection to link a mobile LAN to the home network from almost anywhere on the earth. Our analysis also showed that the Inmarsat-ISDN link behaves almost like the null-modem serial link (very low BER) under good weather conditions. The protocol boosters do not improve the communication for this type of channel but will limit the maximum throughput data transmission rate of the channel based on the proportion of parity generated by the forward erasure correction booster.

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